quantities at a cost of about $100 per thousand cubic feet. The Navy Department is now erecting a large plant to extract helium by the Linde process.

A third experimental plant has been erected at Petrolia, using a process worked out by Norton, a brilliant engineer with a very thorough knowledge of thermodynamics. His process is theoretically sound, but he had never been able to finance its development. Norton is a protégé of Cottrell, of the Bureau of Mines, and the latter insisted that Norton be given money to erect a plant. This is now in operation, and while it has as yet produced helium of no higher concentration than 16 or 17 per cent, its workings are being continually improved and the indications are that it also will be successful. The encouragement of the Norton process is Cottrell's chief contribution to the helium problem. Another man who contributed largely to the success of the undertaking was G. O. Carter, of the Navy Department, Bureau of Steam Engineering. He had formerly been associated with the Linde company, and I believe that his advice and experience were most helpful. Burrell, as head of the American University experiment station, had general charge of the whole problem, and was very efficient; but the man to whom probably the most credit belongs is Sir William Ramsay, who first suggested the use of helium for this purpose.

In our laboratory my chief assistant was C. W. Seibel. H. C. Allen, P. V. Faraghar, F. W. Bruckmiller and Emily Berger were also very active in the matter.

The Earth-Moon Theory.

LeRoy Hughbanks.

GENERAL INTRODUCTION.

Before beginning our discussion of the earth-moon theory it will perhaps be profitable for us to survey briefly a few general facts and characteristics of our moon.

In the following table the volume, surface, mass and density of the earth equals one.

Table of the Moon.

Siderial period	27 days, 7 hours, 43 minutes.
Distance fom the earth	237,300 miles.
Diameter	2,160 miles.
Surface	0.074.
Volume	0.00234.
Mass	0.0128.
Density	0.63.
Axial rotation	27 days, 7 hours, 43 minutes.
Force of gravity (fall)	2.48 feet in 1 second.
Velocity in orbit	2,273 miles per hour.

The moon has always been an object of beauty and interest in the nightly heavens. To the naked eye she presents a soft, silvery luster, and many are they who in ages past have worshiped at her shrine. Old Omar of the East paid homage to her in his poetry, and many another in later days have sung of her transcendent glory.

There are a few mountain chains, hundreds of hills and valleys—numerous systems of radiating streaks—and over thirty thousand ring mountains of all sizes from a mile in diameter to sixty times that.

All details of the lunar surface have been mapped and named. Hevelius (1611-'87), of Danzig, made the first map of the moon, and Schmidt (1825-'84), of Athens, the last. The recent photographic atlases of the Lick and Paris observatories show the lunar surface very satisfactorily, and Ritchey (1864) attained even greater success with the Yerkes telescope. Changes on the moon, if at all, are on a very small scale—too minute for detection with present instruments.

HISTORY OF TREATMENT.

The first treatment of the moon was empirical, but the second treatment was founded on the law of gravitation. The modern history of the moon begins with that illustrous natural philosopher, Sir Isaac Newton. Hipparchus left us a considerable amount of valuable data concerning the motion of the moon. The work of his predecessors did not embrace more than the mean motion of the moon and its nodes. Hipparchus made the following valuable discoveries.

1. The eccentricities of the moon's orbit.
2. Motion of the perigee and apogee.
3. The numerical determination of the elements of the moon's motion.

The discovery of eviction was made by Ptolemy.

As was stated above, the modern lunar theory commenced with Newton, and consists in determining the motion of the moon deductively from the theory of gravitation.

He explained "The elliptic motion of two mutually attracting bodies round their common center of gravity" by geometrical constructions. The problem was one of determining the variations from the elliptical motion which would be produced by a third body. Such constructions could lead only to approximate results. This was left for pure mathematicians and was a problem of pure algebra.

THE EARTH-MOON THEORY.

"The moon," says Prof. Percival Lowell, "did not originate as a separate body, but had its birth in a rib of earth." Doctor Lowell is an ardent supporter of "the earth-moon theory," and his views and deductions are frankly stated in his two last scientific works, "Mars as the Abode of Life" and "Evolution of Worlds," both of which are publications of the Macmillan Company, New York.

Prof. E. C. Pickering, of Harvard College observatory, says: "If we were to observe the earth from a point in space one thousand miles northeast of New Zealand, the land area surrounding the spot would appear nearly circular."

Mr. William Thayer Jordan, in an article entitled "The Form of the Earth," *Scientific American Supplement,* December 14, 1912, is of the opinion, however, "that the advocates" of the "earth-moon theory" had better look for evidence of the moon's detachment on the highlands of Tibet rather than from the Pacific ocean.

Lord Kelvin and Sir George Darwin have long held that the moon had a terrestrial origin. The publication of their many papers and memoirs along this line of research are some of the most exquisite pieces of scientific literature ever given to the technical world.

Prof. Thomas C. Chamberlain, of the University of Chicago, in his excellent lecture on "The Evolution of the Earth," states that the mathematical calcu-

lations of Mr. Darwin are trifling, though we must confess that if this be true they have stood the test of scientific investigators for many decades. For a clear satement of the views held in regard to the moon's origin by Prof. George Darwin we will quote from the last two paragraphs of his celebrated work on "Tides":

"INFLUENCE OF TIDAL FRICTION ON THE EVOLUTION OF THE SOLAR SYSTEM.

"According to the nebular hypothesis, the planets and the satellites are portions detached from contracting nebulous masses. In the following discussion that hypothesis will be accepted in its main outline, and we shall examine what modifications are necessitated by the influence of tidal friction. It may be shown that the reaction of the tides raised in the sun by the planets must have had a very small influence in changing the dimensions of the planetary orbits round the sun. From a consideration of numerical data with regard to the solar system and the planetary subsystems it appears improbable that the planetary orbits have been sensibly enlarged by tidal friction since the origin of the several planets, but it is possible that some very small part of the eccentricities of the planetary orbits is due to this cause. From arguments similar to those advanced with regard to the solar system as a whole, it appears unlikely that the satellites of Mars, Jupiter and Saturn originated very much nearer the present surfaces of the planets than we now observe them; but the data being insufficient, we cannot feel sure that the alteration of the dimensions of the orbits of these satellites has not been considerable. It remains, however, nearly certain that they cannot have first originated almost in contact with the present surfaces of the planets, in the same way as in the preceding sketch, and has been shown to be probable with regard to the moon and earth. Numerical data concerning the distribution of moment of momentum in the several planetary subsystems exhibit so striking a difference between the terrestrial system and those of the other planets that we should from this alone have grounds for believing that the modes of evolution have been considerably different. The difference appears to lie in the genesis of the moon close to the present surface of the planet, and we shall see below that solar tidal friction may be assigned as a reason to explain how it has happened that the terrestrial planet had contracted to nearly its present dimensions before the genesis of a satellite, but that this was not the case with the exterior planets. The efficiency of solar tidal friction is very much greater in its action on the nearer planets than on the further ones. The time, however, during which solar tidal friction has been operating on the external planets is probably much longer than the period of its efficiency for the interior ones, and a series of numbers proportional to the total amount of rotation destroyed in the several planets would present a far less rapid decrease as we recede from the sun than numbers simply expressive of the efficiency of tidal friction at the several planets. Nevertheless it must be admitted that the effect of solar tidal friction produced on Jupiter and Saturn has not been nearly so great as on the interior planets; and, as already stated, it is very improbable that so large an amount of momentum should have been destroyed as to materially affect the orbits of the planets round the sun."

We will now examine how the differences of distance from the sun would be likely to affect the histories of the several planetary masses. According to the nebular hypothesis, a planetary nebula contracts, and rotates quicker as it contracts. The rapidity of the revolution causes it to become unstable, or perhaps an equatorial belt gradually detaches itself. It is immaterial which of these two really takes place. In either case the separation of that part of the mass which before the change had the greatest angular momentum permits the central portion to resume a planetary shape. The contraction and the increase of rotation proceed continually until another portion is detached, etc. There thus reoccur at intervals a series of epochs of instability or of abnormal change. Now tidal friction must diminish the rate of increase of

rotation due to contraction, and therefore if tidal friction and contraction are at work together the epochs of instability must reoccur more rarely than if contraction alone acted. If the tidal retardation is sufficiently great the increase of rotation due to contraction will be so far counteracted as never to permit an epoch of instability to occur.

Since the rate of retardation due to solar tidal friction decreases rapidly as we recede from the sun, these considerations accord with what we observe in the solar system. For Mercury and Venus have no satellites, and there is a progressive increase in the number of satellites as we recede from the sun. Moreover, the number of satellites is not directly connected with the mass of the planet, for the earth has relatively by far the largest satellite of the whole system. Whether this be the true cause of the observed distribution of satellites amongst the planets or not, it is remarkable that the same cause also affords an explanation, as we shall now show, of that difference between the earth with the moon and the other planets with their satellites which has caused tidal friction to be the principal agent of change with the former but not with the latter.

In the case of the contracting terrestrial mass we may suppose that there was for a long time nearly a balance between the retardation due to solar tidal friction and the acceleration due to contraction, and that it was not until the planetary mass had contracted to nearly its present dimensions that an epoch of instability could occur. It may also be noted that if there be two planetary masses which generate satellites, but under very different conditions as to the degree of condensation of the masses, the two satellites will be likely to differ in mass. We cannot, of course, tell which of the two planets would generate the larger satellite. Thus, if the genesis of the moon was deferred until a late epoch in the history of the terrestrial mass, the mass of the moon relatively to the earth would be likely to differ from the mass of the other satellites relative to their planets. If the contraction of the planetary mass be almost completed before the genesis of the satellites, tidal friction, due jointly to the satellites and to the sun, will thereafter be the great cause of change in the system; and thus the hypothesis that it is the sole cause of change will give an approximately accurate explanation of the motion of the planet and satellite at any subsequent time. We have already seen the theory that tidal friction has been the ruling power in the evolution of the earth and moon coördinates the present motion of the two bodies and carries us back to an initial state when the moon first had its separate existence as a satellite; and the initial configuration of the two bodies is such that we are led to believe that the moon is a portion of the primitive earth detached by rapid rotation or other causes. There seems to be some reason to suppose that the earliest form in which the moon had a separate existence was as a ring or chain of meteorites; but this condition precedes that to which the dynamical investigation leads back.

Let us now turn to the other planetary subsystems. The satellites of the larger planets revolve with short periodic times. This admits of a simple explanation, for the smallness of their masses would have prevented tidal friction from being a very efficient cause of change in the dimensions of their orbits, and the largeness of the planets' masses would have caused them to proceed slowly in their evolution. If the planets be formed from change of meteorites

or of nebulous matter, their rotation has arisen from the excess of orbital momentum of the exterior over that of the interior matter. As we have no means of knowing how broad the chain may have been in any case, nor how much it may have closed in on the sun in course of concentration, we are unable to compute the primitive angular momentum of a planet. A rigorous method of comparison of the primitive rotation of the several planets is thus wanting. If, however, the planets were formed under similar conditions, then we should expect to find the exterior planets now rotating more rapidly than the interior ones. On making allowance for the different degrees of concentration of the planets, this is the case. That the inner satellites of Mars revolve with a period of less than a third of the planet's rotation is perhaps the most remarkable fact in the solar system. The theory of tidal friction explains this perfectly; and this will be the ultimate fate of all satellites, because the solar tidal friction retards the planetary rotation without directly affecting the satellites' orbital motion. Numerical comparison shows that the efficiency of solar tidal friction in retarding the terrestrial and Martian rotation is of about the same degree of importance, notwithstanding the much greater distance of the planet Mars. In the above discussion it will have been apparent that the earth and moon do actually differ from the other planets to such an extent as to permit tidal friction to have been the most important factor in their history.

By an examination of the probable effects of solar tidal friction on a contracting planetary mass we have been led to assign a cause for the observed distribution of satellites in the solar system, and this again has itself afforded an explanation of how it happened that the moon so originated that the tidal friction of the lunar tides in the earth should have been able to exercise so large an influence. We have endeavored not only to set forth the influence which the tidal friction may have, and probably has had, in the history of the system, if sufficient time be granted, but also to point out what effects it cannot have produced. These investigations afford no ground for the rejection of the nebular hypothesis; but while they present evidences in favor of the main outlines of that theory, they introduce modifications of considerable importance. Tidal friction is a cause of change of which Laplace's theory took no account; and although the activity of that cause may be regarded as mainly belonging to a later period than the events described in the nebular hypothesis, yet it seems that its influence has been of great and in one instance of even paramount importance in determining the present condition of the planets and their satellites. Throughout the whole of this discussion it has been, however, supposed that sufficient time is at our disposal. Sir W. Thomson and others have, however, adduced reasoning which goes to show that the history of the solar system must be comprised within a period of considerably less than a hundred million years. It would perhaps be permature to accept this as the final and definite conclusion of science. If, however, it be confirmed, we shall only be permitted to accept the doctrine that tidal friction has effected considerable modification in the configuration of the moon and earth, and must reject the earlier portion of the history sketched above.

There is another scientific school that holds the moon had a separate origin from that of the earth. Perhaps chief among these gentlemen is Prof. T. J. J. See, United States government astronomer, but he is not alone in his contentions. We also find listed among the adherents of this theory Mr. William

Thayer Jordan; Prof. Henri Jules Poincare, of the University of Paris, who used Doctor See's scholarly work, "Researches on Cosmical Evolution," volume 11; Mr. William Huggins, former president of the Royal Society; and Professor Strongen, of Copenhagen.

In an address delivered before the California Academy of Science, August 7, 1911, Professor See had the following to say in regard to the origin of the moon:

"THE CAPTURE OF THE MOON BY THE EARTH.

"The case of the terrestrial moon is of special interest, because it is relatively by far the largest of our satellites and was formerly supposed by Lord Kelvin and Sir George Darwin to have had an exceptional origin. But it was shown by me in 1909 (A. N., No. 343) that the moon was formed like the other satellites, and is in fact a planet which the earth captured from space, just as the other satellites were captured by their several planets. We shall not here go into the details of the moon's origin, beyond pointing out the reasons why a terrestrial origin of the moon is impossible:

"(1) The rupture of the earth's figure of equilibrum, which Darwin assumed to account for the origin of the moon, postulates a primitive rotation in less than three hours, or nine times faster than at present. From the causes which produce planetary rotations, as set forth above, we know that no such rapid rotation could have existed in the case of the earth.

"(2) Even if such rapid rotation had existed, the matter detached from the earth would have taken the form of a swarm of small bodies, and these meteorites never could have united into one mass, as now observed in our actual moon.

"(3) The satellites of the other planets are recognized to be captured bodies, and the same process naturally will have operated in giving the earth a satellite, even if it is of exceptionally large mass. It should be especially noted that the large mass presents no difficulty to the capture theory. The anomaly lies in the small size of the earth, since several of the satellites of Jupiter and Saturn are fully as large as the moon, while those of Uranus and Neptune are not enormously smaller.

"(4) In Darwin's celebrated graphical method for tracing the moon back to the earth, it is found to be impossible to bring the two globes close together, because at nearest approach a space of over 4,000 miles intervenes between the surfaces which cannot be bridged over. This contradiction to the terrestrial theory indicates that it is vitiated by an error, and must be unconditionally given up. For these four weighty reasons we conclude that our moon can be nothing else than a planet which came to us from the heavenly spaces. It follows also that the earth always did rotate in about the same time as at present, and has never suffered retardation from about three hours, as Darwin inferred. This simplifies very considerably many problems of geology, and brings the cosmogony of the earth and moon into harmony with that found in the rest of the solar system and in the sidereal universe.

"THE ORIGIN OF THE LUNAR CRATERS AND MARIA.

"Ever since Galileo's discovery of the mountains on the moon it has been a problem for astronomers to explain the craters and other phenomena on the lunar surface. Notwithstanding the fact that the lunar craters are totally different from those on the earth, it has been believed until very recently that they had a volcanic origin. It turns out, however, that the lunar craters are due to impact of smaller bodies against the lunar surface; and this explains the sunken character of the craters, which are all below the normal level of the lunar surface; the small volume of the walls in comparison with the crater basins; the steepness of the inner walls, while the outer ones have a more gradual slope; the central peaks, which are residues of the satellites that produced the craters; the superposition of one crater over another; and many other phenomena which show that impact and not volcanic

action has produced the mountains on the surface of the moon. In the same way it is shown that the *maria* are due to conflagrations which have melted down to a dead level considerable areas of the lunar surface, only the more prominent walls here and there surviving as ghost craters. It is a very remarkable fact that can scarcely escape the notice of the sagacious historian of the future, that prior to my work on 'Earthquakes and Mountain Formation' (Proc. Am. Philos. Soc., Philadelphia, 1906-'08), terrestrial mountains were erroneously explained by secular cooling and contraction of the earth, whereas they are really formed by the leakage of the oceans and the expulsion of lava under the land, and the mountain ridges, therefore, run as great walls along the border of the ocean, as in the typical case of the Andes in South America. The current explanation of terrestrial mountain formation was thus erroneous. The new theory that our mountains are formed by the sea has, however, already been very generally accepted. On the other hand, the lunar craters were supposed to be of a volcanic origin, whereas they really were due to impact. Thus, wonderful as it may seem, the causes assigned in both cases were erroneous. Besides the evidence of general character above cited, the theory as to the origin of the lunar craters by impact now rests on an absolute proof of mathematical kind, as follows. It is shown by the researches of Lehman-Filhe's (A. N., 3479-3490) and Strongen (A. N., 3897) that increase of the central mass of the planet by the downfall of cosmical dust will decrease the mean distance of the satellites, but not the eccentricities of its orbit. It is shown in my researches (volume 2, 1910) that the eccentricity can be diminished only by the action of a resisting medium such as operated in the capture of the satellites. As the eccentricities of the satellites' orbits usually are evanescent, and it is shown that they have been destroyed by the action of a resisting medium, we should expect the moon surface to bear witness to this process of cosmical bombardment by which the orbits of the satellites have been rounded up. Thus indentations analogous to the lunar craters ought to exist, and as they are all of one type their origin must be assigned to the impact of smaller satellites against the lunar surface. Our proof of the origin of the lunar craters is therefore essentially an absolute proof which admits of no dispute. If it be asked why indentations similar to the lunar craters were not produced on the earth, our answer is that such terrestrial craters due to impact did exist before geological history began, but they have since been quite obliterated by the effects of the oceans and atmosphere, while modern terrestrial mountains of a totally different type have since been developed along the borders of our seas by the leakage of the oceans. These manifold errors afford us an impressive warning as to the worthlessness of traditional opinion, because so much of our reasoning in physical science heretofore has been based on a false premise. Finally, it may be remarked that the satellites of Jupiter and Saturn are variable, as if covered by *maria* like our own moon, so that the conflagrations which melted areas and produced *maria* on our satellite have also occurred elsewhere in accordance with the requirements of this simple theory."

As can readily be seen, the astronomical world is at variance on this subject, men of learning and serious scientific attainment on either side contending for the particular bulk of evidence which they feel will insure a correct solution of the problem. Dr. Kennedy Duncan, for a number of years at the University of Kansas, thought "the planetisimal hypothesis," as carefully worked out by Prof. T. C. Chamberlain and Dr. Horace Moulton, would give us a satisfactory solution to the origin of the sun, planets and satellites. The work of these men has been very productive and we will await with much interest their further research.